THEREFORE WHAT IS CLAIMED IS:

1. A composite material, comprising:

a substrate and a well ordered colloidal crystal self-assembled on a surface of said substrate, said well ordered colloidal crystal defining a pre-selected pattern, said colloidal crystal including colloidal particles of selected shape and size.

2. The composite material according to claim 1 wherein said substrate includes any of indentations and channels of pre-selected size and shape in said surface defining a pre-selected surface relief pattern, and wherein said well ordered colloidal crystal is formed by self-assembly of said colloidal particles in any of said indentations and channels to form said pre-selected pattern.

3. The composite material according to claim 2 wherein said substrate is selected from the group consisting of insulators, semiconductors, glasses, polymers and metals.

4. The composite material according to claim 2 wherein said colloidal particles are spherical colloidal particles having a diameter in a range from about 0.1 to about 5 microns.

5. The composite material according to claim 4 wherein said spherical colloidal particles are silicon dioxide (SiO_2) microspheres.

6. The composite material according to claim 1 wherein said colloidal particles are consolidated by thermal sintering or hydrothermal treatment in aqueous base or silica chemical vapor deposition necking of the colloidal particles.

7. The composite material according to claim 6 wherein said consolidated colloidal crystal is infiltrated with a material having a selected refractive index.

8. The composite material according to claim 7 wherein said colloidal

particles are removed producing an inverted infiltrated colloidal crystal embedded on said substrate.

9. The composite material according to claim 8 wherein said inverted infiltrated colloidal crystal is a photonic crystal.

10. The composite material according to claim 9 wherein said photonic crystal is characterized by a photonic bandgap.

11. The composite material according to claim 9 including means for coupling light into said colloidal crystal or said inverted infiltrated colloidal crystal.

12. The composite material according to claim 11 including means for coupling light out of said colloidal crystal said inverted infiltrated colloidal crystal.

13. The composite material according to claim 12 wherein said means for coupling light into and out of said colloidal crystal are optical fibers and or waveguides attached to said substrate.

14. The composite material according to claim 13 wherein said means for coupling light into and out of said colloidal crystal or said inverted colloidal crystal are optical fibers and or waveguides.

15. The composite material according to claim 2 including a layer of a material formed on top of said colloidal crystal and said surface.

16. The composite material according to claim 15 wherein said material is made of the substrate material so that said well ordered colloidal crystal is embedded in said substrate.

17. A method of synthesizing composite material comprised of a highly ordered colloidal crystal and a substrate, the method comprising the steps of:

a) providing a substrate having a surface with a selected surface relief pattern;

b) applying masking means to a portion of said surface so that said masking means is resting on raised portions of said surface;

c) applying a liquid dispersion containing colloidal particles of selected shape and size to an unmasked portion of said surface wherein said colloidal particles are drawn under said masking means by capillary forces and self-assemble into a substantially ordered colloidal crystal in void spaces on said surface defined by said relief pattern and said masking means; and

d) removing said masking means.

18. The method according to claim 17 wherein said masking means has a substantially planar surface so that said planar surface is resting on raised portions of said surface when said masking means is applied to said surface.

19. The method according to claim 17 wherein said substrate is selected from the group consisting of insulators, semiconductors, glasses, polymers and metals.

20. The method according to claim 17 wherein said colloidal particles are spherical colloidal particles having a diameter in a range from about 0.1 to about 5 microns.

21. The method according to claim 21 wherein said spherical colloidal particles are made of silicon dioxide (SiO_2).

22. The method according to claim 17 including a step of consolidation of the colloidal crystal by thermal sintering or hydrothermal treatment in aqueous base and silica chemical vapor deposition resulting in necking of the colloidal particles.

23. The method according to claim 22 including a step of infiltration of the colloidal crystal with a selected material followed by a step of inversion to remove the colloidal particles to produce an inverted colloidal crystal pattern on said substrate.

24. The method according to claim 23 wherein said inverted colloidal crystal is a photonic crystal.

25. The method according to claim 24 wherein a ratio of air to the selected material is selected so that said photonic crystal is characterized by a photonic

bandgap.

26. The method according to claim 17 including a step of depositing a layer of a selected material on top of the surface of said substrate containing said inverted colloidal crystal pattern.

27. The method according to claim 26 including a step of producing a selected surface relief pattern on a top surface of said layer of said selected material and repeating steps b), c) and d) according to claim 1 to produce a substrate with more than one inverted colloidal crystal pattern embedded within said substrate.

28. The method according to claim 27 wherein said more than one inverted colloidal crystal are photonic crystals embedded within said substrate.

29. The method according to claim 17 wherein said surface relief pattern is produced using one of soft lithography and photolithography.

30. A method of synthesizing composite material of a colloidal crystal and a substrate, comprising:

a) providing a substrate having a surface with a selected surface relief pattern; and

b) applying a liquid dispersion containing colloidal particles of selected shape and size onto said surface and spinning said substrate whereby colloidal particles are swept across said surface and self-assemble in void spaces on said surface defined by said relief pattern.

31. The method according to claim 30 wherein said substrate is selected from the group consisting of insulators, semiconductors, glasses, polymers and metals.

32. The method according to claim 30 wherein said colloidal particles are spherical colloidal particles having a diameter in a range from about 0.1 to about 5 microns.

33. The method according to claim 32 wherein said spherical colloidal particles are made of silicon dioxide (SiO_2).

34. The method according to claim 30 including a step of consolidation of the colloidal crystal by thermal sintering or hydrothermal treatment in aqueous base and silica chemical vapor deposition resulting in necking of the colloidal particles.

35. The method according to claim 34 including a step of infiltration of the colloidal crystal with a selected material followed by a step of inversion to remove the colloidal particles to produce an inverted colloidal crystal pattern on said substrate.

36. The method according to claim 35 wherein said inverted colloidal crystal is a photonic crystal.

37. The method according to claim 36 wherein a ratio of air to the selected material is selected so that said photonic crystal is characterized by a photonic bandgap.

38. The method according to claim 30 including a step of depositing a layer of a selected material on top of the surface of said substrate containing said inverted colloidal crystal pattern.

39. The method according to claim 38 including a step of producing a selected surface relief pattern on a top surface of said layer of said selected material and repeating steps b), c) and d) according to claim 1 to produce a substrate with more than one inverted colloidal crystal pattern embedded within said substrate.

40. The method according to claim 39 wherein said more than one inverted colloidal crystal are photonic crystals embedded within said substrate.

41. The method according to claim 30 wherein said surface relief pattern is produced using soft lithography.

42. A method of synthesizing composite material comprised of a colloidal crystal and a substrate, comprising:

a) providing a substrate having a substantially planar surface;

b) applying masking means to a portion of said surface, said masking means having a surface with a selected surface relief pattern with said surface

being adjacent to said planar surface;

c) applying a dispersion containing colloidal particles of selected shape and size to an unmasked portion of said surface wherein said colloidal particles are drawn under said masking means by capillary forces and forming into a colloidal crystal by self-assembly in void spaces on said surface defined by said relief pattern and said planar surface;

d) removing said masking means;

e) consolidating the colloidal crystal by one of thermal sintering, hydrothermal treatment and silica chemical vapor deposition to produce necking of the colloidal particles;

f) infiltrating the colloidal crystal pattern formed on the substrate with a material having a selected refractive index; and

g) removing the colloidal particles to produce an inverted colloidal crystal pattern embedded on said substrate.

43. The method according to claim 42 wherein said substrate is selected from the group consisting of insulators, semiconductors, glasses, polymers and metals.

44. The method according to claim 42 wherein said colloidal particles are spherical colloidal particles having a diameter in a range from about 0.1 to about 5 microns.

45. The method according to claim 44 wherein said spherical colloidal particles are made of silicon dioxide (SiO_2).

46. The method according to claim 42 wherein said inverted colloidal crystal pattern is a photonic crystal.

47. The method according to claim 46 wherein said photonic crystal is characterized by a photonic bandgap.

48. The method according to claim 46 including attaching light coupling means to said substrate for coupling light into said colloidal crystal or said inverted infiltrated colloidal crystal.

49. The method according to claim 47 including attaching light coupling means to said substrate for coupling light into said colloidal crystal or said inverted infiltrated colloidal crystal.

50. The method according to claim 42 wherein said surface relief pattern includes at least one indentation of selected geometry and depth formed in the surface.

51. The method according to claim 50 wherein said at least one indentation is a plurality of indentations across said surface forming a selected pattern.

52. A method of synthesizing composite material of a colloidal crystal and a substrate, comprising:

a) providing a substrate having a surface with a selected surface relief pattern;

b) dipping said substrate into a liquid dispersion containing colloidal particles of selected shape and size, wherein said liquid dispersion includes a solvent having an effective evaporation rate, and wherein evaporation of said solvent induces directional mass transport of said colloidal particles within said relief pattern, wherein said colloidal particles spontaneously self-assemble and crystallize between raised features of said surface relief pattern; and

c) removing said substrate from said liquid dispersion.

53. The method according to claim 52 wherein said surface relief pattern includes elongate channels extending across said surface, and wherein said substrate is dipped into said liquid dispersion such that said elongate channels are substantially vertical.

54. The method according to claim 52 wherein said elongated channels are inclined at a pre-selected angle with respect to the vertical.

55. The method according to claim 52 wherein said surface relief pattern is produced by placing a PDMS elastomeric stamp patterned with a parallel array of micron scale rectangular-shaped micro-channels into conformal contact with said surface of the substrate, infiltrating an effective polymeric material into said micro-channels, polymerizing said polymeric material and then removing said

PDMS elastomeric stamp leaving behind said surface relief pattern comprising rectangular-shaped micro-channels.

56. The method according to claim 53 wherein said effective polymeric material includes silica sol (from tetramethoxysilane and 0.1N oxalic acid (3:1 w/w)), organic modified silica sol (from mixture of 3-(glycidoxypropyl)trimethoxysilane, tetramethoxysilane and 0.1N oxalic acid 5:1:1 w/w) or pre-polymer (NOA-60 or NOA-73 polyurethane.

57. The method according to claim 52 wherein said liquid dispersion includes an alcohol.

58. The method according to claim 57 wherein said alcohol is ethanol.

59. The method according to claim 52 wherein said substrate is withdrawn from said liquid dispersion at a pre-selected rate.

60. The method according to claim 59 wherein said colloidal dispersion includes a 2-5wt% ethanolic suspension of mono-disperse silica micro-spheres that have diameters in a size range from about 350 nm to about 2500 nm diameter.

61. The method according to claim 60 wherein the rate of withdrawal of the patterned substrate from the ethanolic suspension is in a velocity range of about 0.5 to about 3 cm/s.

62. The method according to claim 61 wherein said particles have diameters in a range from about 600 nm to about 2500 nm, including stirring said liquid dispersion.

63. The method according to claim 60 wherein said surface relief pattern is formed directly in said surface.

64. The method according to claim 60 wherein said surface relief pattern is produced in a mold that is affixed to the surface of the substrate.

65. A method for producing a film of colloidal particles on a planar surface of a substrate, comprising the steps of:

a) dipping a substrate into a liquid dispersion containing colloidal particles of selected shape and having a mean diameter in a range from about 600 nm to about 2500 nm, said liquid dispersion including a solvent having a pre-selected rate of evaporation;

b) agitating said liquid dispersion in such a way so as to reduce sedimentation of said colloidal particles but not to disturb a meniscus that is formed between the planar surface and the liquid dispersion of colloidal particles, wherein evaporation of said solvent induces said colloidal particles to spontaneously self-assemble and crystallize on said planar surface; and

c) removing said substrate from said liquid dispersion.

66. The method according to claim 65 wherein said rate of evaporation is controlled by controlling the temperature of the liquid dispersion.

67. The method according to claim 65 wherein said colloidal particles are mono-disperse spherical particles.

68. The method according to claim 67 wherein said mono-disperse spherical particles are silica spheres and said film is an opal film.

69. The method according to claim 65 including a step of consolidation of the colloidal crystal by one of thermal sintering, hydrothermal treatment in aqueous base and silica chemical vapor deposition resulting in necking of the colloidal particles.

70. The method according to claim 69 including a step of infiltration of the colloidal crystal film formed on the substrate with a selected material followed by a step of inversion to remove the colloidal particles to produce an inverted colloidal crystal film on said substrate.

71. The method according to claim 70 wherein said selected material has a refractive index equal to or greater than about 3.2 so that a difference in refractive index between the selected material and air in the inverted colloidal crystal pattern is at least about 2.2.

72. The method according to claim 71 wherein said inverted colloidal crystal film has a photonic bandgap.

73. The method according to claim 65 including lithographically patterning said inverted colloidal crystal pattern to produce therein optical circuits.

74. The method according to claim 65 wherein the step of agitating said liquid dispersion includes stirring or producing a thermal convection gradient in said liquid.

75. A method of synthesizing composite material comprised of a colloidal crystal and a substrate, comprising:

a) providing a substrate having a substantially planar top surface;

b) applying masking means to a portion of said top surface, said masking means having a surface with a first surface relief pattern with said surface being adjacent to said planar surface;

c) applying a dispersion containing colloidal particles of selected shape and size to an unmasked portion of said top surface wherein said colloidal particles are drawn under said masking means by capillary forces and form a first colloidal crystal by self-assembly in void spaces between said surface and said masking means;

d) infiltrating a polymer into void spaces present between the colloidal particles in said colloidal crystal and curing said polymer; and

e) removing said masking means wherein said colloidal crystal pattern on said substantially flat planar surface defines a second surface relief pattern having raised portions.

76. The method according to claim 75 including applying a dispersion containing second colloidal particles of selected shape and size to said top surface wherein said second colloidal particles are drawn between said raised portions by capillary forces and form a second colloidal crystal by self-assembly between said raised portions.

77. The method according to claim 76 including removing said cured polymer.

78. The method according to claim 76 wherein said first colloidal particles are silica microspheres having a first diameter and said second colloidal particles are silica microspheres having a second diameter.

79. The method according to claim 78 wherein said second relief pattern in said masking means is a plurality of parallel, spaced apart channels so that the first colloidal crystal includes a plurality of substantially parallel and spaced apart first longitudinal beams formed from the colloidal spheres having said first diameter and located between adjacent first longitudinal beams are substantially parallel, second longitudinal beams formed from the colloidal spheres having said second diameter.

80. The method according to claim 78 wherein said second diameter is less than said first diameter.

81. The method according to claim 75 wherein after step c) said first colloidal crystal is dried prior to infiltrating said first colloidal crystal with said polymer.

82. The method according to claim 81 wherein said polymer is an ultra-violet curable polyurethane.

83. The method according to claim 82 including removing said cured polyurethane by heating said composite material.

84. The method according to claim 75 wherein the step of applying a dispersion containing second colloidal particles of selected shape and size to said top surface includes dipping said substrate into a liquid dispersion containing said second colloidal particles of selected shape and size, wherein said liquid dispersion includes a solvent having an effective evaporation rate, and wherein evaporation of said solvent induces directional mass transport of said colloidal particles between adjacent first longitudinal beams defined by said first colloidal crystal, wherein said colloidal particles spontaneously self-assemble and crystallize between raised features of said first colloidal crystal, and removing said substrate from said liquid dispersion.

85. The method according to claim 84 wherein said substrate is dipped into

said liquid dispersion so that said elongate channels are substantially vertical.

86. The composite material according to claim 4 wherein said spherical colloidal particles are selected from the group consisting of inorganic microspheres and polymer microspheres.

87. A composite material comprised of a colloidal crystal and a substrate, produced by a method comprising the steps of:

a) providing a substrate having a surface with a selected surface relief pattern;

b) applying masking means to a portion of said surface so that said masking means is resting on raised portions of said surface;

c) applying a liquid dispersion containing colloidal particles of selected shape and size to an unmasked portion of said surface wherein said colloidal particles are drawn under said masking means by capillary forces and self-assemble into a substantially ordered colloidal crystal in void spaces on said surface defined by said relief pattern and said masking means; and

d) removing said masking means.

88. A composite material comprised of a colloidal crystal and a substrate, produced by a method comprising the steps of:

a) providing a substrate having a surface with a selected surface relief pattern; and

b) applying a liquid dispersion containing colloidal particles of selected shape and size onto said surface and spinning said substrate whereby colloidal particles are swept across said surface and self-assemble in void spaces on said surface defined by said relief pattern.

89. A composite material comprised of a colloidal crystal and a substrate, produced by a method comprising the steps of:

a) providing a substrate having a surface with a selected surface relief pattern;

b) dipping said substrate into a liquid dispersion containing colloidal particles of selected shape and size, wherein said liquid dispersion includes a solvent having an effective evaporation rate, and wherein evaporation of said solvent induces directional mass transport of said colloidal particles within said relief pattern, wherein said colloidal particles spontaneously self-assemble and

crystallize between raised features of said surface relief pattern; and

c) removing said substrate from said liquid dispersion.

90. The product according to claim 89 wherein the method includes withdrawing said substrate from said liquid dispersion at a pre-selected rate.

91. A product comprised of a film of colloidal particles on a planar surface of a substrate, produced by a method comprising the steps of:

a) dipping a substrate into a liquid dispersion containing colloidal particles of selected shape and having a mean diameter in a range from about 600 nm to about 2500 nm, said liquid dispersion including a solvent having a pre-selected rate of evaporation;

b) agitating said liquid dispersion in such a way so as to reduce sedimentation of said colloidal particles but not to disturb a meniscus that is formed between the planar surface and the liquid dispersion of colloidal particles, wherein evaporation of said solvent induces said colloidal particles to spontaneously self-assemble and crystallize on said planar surface; and

c) removing said substrate from said liquid dispersion.

92. A composite material comprised of a colloidal crystal and a substrate, produced by a method comprising the steps of:

a) providing a substrate having a substantially planar top surface;

b) applying masking means to a portion of said top surface, said masking means having a surface with a first surface relief pattern with said surface being adjacent to said planar surface;

c) applying a dispersion containing first colloidal particles of selected shape and size to an unmasked portion of said top surface wherein said first colloidal particles are drawn under said masking means by capillary forces and form a first colloidal crystal by self-assembly in void spaces between said surface and said masking means;

d) infiltrating a polymer into void spaces present between the colloidal particles in said colloidal crystal and curing said polymer;

e) removing said masking means wherein said colloidal crystal pattern on said substantially flat planar surface defines a second surface relief pattern having raised portions; and

f) applying a dispersion containing second colloidal particles of selected

shape and size to said top surface wherein said second colloidal particles are drawn between said raised portions by capillary forces and form a second colloidal crystal by self-assembly between said raised portions.

93. The product according to claim 92 wherein said first colloidal particles are spherical colloidal particles having a first mean diameter, and wherein said second colloidal particles are spherical colloidal particles having a second mean diameter, wherein said first diameter is smaller than said first diameter.

94. The product according to claim 93 wherein said product is characterized by a reflectance spectrum comprised of a first reflectance peak having a wavelength position and bandwidth determined by the diameter of said first spherical particles and a second reflectance peak having a wavelength position and bandwidth determined by the diameter of said second spherical particles.

95. The product according to claim 93 wherein said first spherical particles have a diameter in a range from about 250 nm to about 600 nm, and wherein said second spherical particles have a diameter in a range from about 601 nm to about 2500 nm.

96. A bi-frequency colloidal crystal diffraction device, comprising:
a substrate and a first array of first colloidal particles of a first size arrayed in elongate, parallel and spaced strips across a top surface of said substrate, and a second array of second colloidal particles of a second size arrayed in elongate, parallel and spaced strips across a top surface of said substrate with each strip of said second array being located between two adjacent strips of said first array, and wherein said first size is different from said second size.

97. The diffraction device according to claim 96 wherein said first colloidal particles are spherical colloidal particles having a first diameter and said second colloidal particles are spherical colloidal particles having a second diameter different from said first diameter, and wherein said device is characterized by a reflectance spectrum comprised of a first reflectance peak having a wavelength position and bandwidth determined by the diameter of said first spherical particles and a second reflectance peak having a wavelength position and bandwidth determined by the diameter of said second spherical particles.

98. The diffraction device according to claim 97 wherein said first spherical particles have a diameter in a range from about 250 nm to about 600 nm, and wherein said second spherical particles have a diameter in a range from about 601 nm to about 2500 nm.

99. A Lincoln Log Wood Pile superlattice, comprising:

a substrate and a first array of first colloidal particles of a first size arrayed in elongate, parallel and spaced strips across a top surface of said substrate, and a second array of second colloidal particles of a second size arrayed in elongate, parallel and spaced strips over top of said first array and being disposed substantially perpendicular to said first array.

100. The Lincoln Log Wood Pile superlattice according to claim 98 wherein said first and second colloidal particles are spherical colloidal particles having a preselected diameter in a range from 250 nm to about 2500 nm.

101. A method of producing a Lincoln Log Wood Pile superlattice, comprising

placing two polymer masks each having a parallel grooves in one face thereof face-to-face contact with said faces with said grooves being pressed together with the grooves in one face perpendicular to the grooves in the other face;

infiltrating a curable polymer into the grooves through capillary action, and curing said polymer and then removing one of said masks;

pressing the other mask against a substrate so said cured polymer is contacted to said substrate, heating said polymer to above a glass transition temperature of the polymer mask, thereafter cooling said polymer and peeling said mask leaving behind a 3-D wood-pile structure on the surface of the substrate; and

exposing said 3-D woodpile structure to a liquid dispersion containing colloidal crystal particles which infiltrate into empty spaces of the wood-pile structure and self-assemble therein.